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The clay mineralogy of some Massachusetts soils developed on till.

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THE CLAY MINERALOGY OF SOME MASSACHUSETTS SOILS DEVELOPED ON TILL

A Thesis Presented

by

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ABSTRACT

X-ray diffraction studies of six soils developed on weathered sections of lower till and unweathered upper tills in Massachusetts revealed that weathering of clay minerals in the less than 2 um size fraction follows a consistent sequence in each profile studied. Chlorite and illite in the C horizons are weathering to vermiculite and a chloritized product in the A and B horizons. As reported by others, this weathering is more complete with proximity to the surface. Interstratified illite/chloritized vermiculite is common in the C horizons of weathered lower tills in western Massachusetts. Mixed-layering was never observed in unweathered upper tills of the state. In soils developed on the lower tills, the interstratification is disrupted in the solum indicating the further weathering of illite layers in the present soil environment. Gibbsite is common to all A and B horizons, present in the C horizons of the lower till soils, but absent in the C horizon of upper till soils.

CHAPTER I

INTRODUCTION

Detailed clay mineralogical studies of New England soils are essentially limited to work performed at the Connecticut Experiment Station by Tamura (1954, 1957, 1958), Sawhney (1958, 1960) and Frink (1965, 1969). Almost nothing is known about soil clay mineralogy in other areas of the region. Generalizations may be made from results of the work in Connecticut; however, few published data are available for the other states.

Krohelski (1976) studied soils developed on two different tills in western Massachusetts. He presents some X-ray diffraction data that confirm the major weathering sequence established earlier by the Connecticut group. That is, micas and chlorite in the parent material are weathering to vermiculite and chloritized products in the A and B horizons. The chloritization process appears to be more complete and stable with proximity to the surface.

Quigley and Martin (1963) published data for soil clays from a soil developed on till in Boston, Massachusetts. They report that chloritization is found to a depth of 55 inches in this soil, and infer that the chloritization in the profile has occurred in the 15,000 years since the retreat of the last ice sheet. An alternative explanation, which they did not consider, may be consistent with evidence suggesting the occurrence of an older, weathered till in parts of New England.

Schafer and Hartshorn (1965) summarized the two-till problem and presented evidence for an older till unit. Since then, Pessl (1967, 1971) and Pessl and Schafer (1968) have studied two tills in Connecticut and southern New Hampshire, concluding that an olive gray and brown till (the "lower" till which contains a weathered or oxidized zone) is common to many parts of New England and that it is probably older than a lighter colored till (the "upper" or "new" till) of the last glaciation.

Denny (1958), Drake (1971), and Goldthwait (1968) have interpreted similar data for tills in New England in another way. They suggest that the two units are subglacial and supraglacial components of one till sheet. After a conference among proponents of different till origins, Goldthwait (1971) notes that the two groups have agreed on an explanation for both sets of data by proposing a three-till solution to the problem. They conclude that an older, weathered till (the lower till) not previously included in Drake's and Goldthwait's theories, is overlain by two components (a basal and an ablation till) of the unweathered, upper till. In most sections, however, only two units are found to occur, explaining the original difficulty in interpreting data from different areas of New England.

Description of Tills

The two major till units are usually recognized in the field by differences in texture and color. Locally they are known as the upper and lower tills. Whenever both are found in contact, the former is always found above the other, hence the terminology.

The lower till contains two easily recognizable zones, an upper weathered (or oxidized) zone and a lower, apparently unweathered zone. The matrix of the weathered zone appears stained or "oxidized." The matrix of unweathered sections is fresh and, occasionally, unweathered mica grains may be observed. Colors are generally olive brown (2.5y 5/4) in the oxidized zone and light olive gray (5y 6/2) in unweathered sections. There are no published accounts of unweathered sections having been observed in or directly beneath a soil profile. The weathered zone is typically thick, 6 to 10 meters being common. Contacts between the two range from a very gradual transition in color to a sharp, clear boundary change. The till in both zones is quite compact, and exhibits bulk densities greater than 1.8 g/cc (Krohelski, 1976). Weathered sections tend to develop Fe- and Mn-stained fissility or platy structure which becomes more widely spaced with depth (Mulholland, 1974). Textures of this till can range from silt loam to sandy loam, depending upon the local bedrock, but usually are at least 10 percent clay.

The upper till is typically more variable, both vertically and laterally. Mulholland (1974) describes two sandy upper tills, one compact and the other loose, in the Ware quadrangle Massachusetts. Most sections of upper till show some degree of sorting. Its mottled or streaky appearance has been explained as a result of its non-homogeneous texture. Campbell (1975) describes three different upper tills of varying texture in the Northfield, quadrangle, Massachusetts. The tills range in texture from loamy sands to silt loams. Campbell attributed the textural variations to differences in bedrock lithology within the quadrangle. The sandy till is loose, the silty till firm, but not dense.

The upper till unit rarely appears weathered to greater than .5 to 1 meters (Schafer and Hartshorn, 1965) and, in most sections, never appears weathered below the soil profile. Colors are quite variable and are dependent on texture, degree of sorting, and the local bedrock lithology. Commonly, the colors are olive gray (5Y 4/2), olive (5Y 5/3), or light gray (5Y 7/2). Bedrock influence is very apparent in some areas of New England. In southeastern Massachusetts, where upper till is found within the Narragansett Basin (Fig. 1), the Pennsylvanian shale and coal beds impart a dark brown, almost black, color to some tills in the area (Peter Fletcher, 1978, pers. commun.).

One of Campbell's (1971) upper tills occurs in the Connecticut River valley in Massachusetts. The till is reddish-brown, resulting from the glacial erosion, communition, and deposition of material from red Triassic-Jurassic sandstone, shale, and conglomerate in the region. Table 1 (from Campbell, 1975) summarizes the characteristics of the two tills as they occur in the Northfield quadrangle, Massachusetts.

Newton (1978) has studied tills in Connecticut, Massachusetts, and New Hampshire. He presents the only chemical and mineralogical data available on tills below the soil profile. His data indicate that garnet weathering is more extensive in the lower till and decreases with depth. K+ content increases with depth, indicating less weathering of K-bearing minerals. The upper tills studied, however, show much less garnet weathering at comparable depths. Clay mineral data also indicate more extensive weathering of the lower till.

The primary objective of the present study is to characterize clay minerals of the less than 2 um size fraction in soils occurring on tills in Massachusetts. Additional investigations are made into the nature of the mineralogy of weathered sections of lower till. Special attention was given to two profiles to contrast soil development on the weathered "lower" till (Site 6) with that of a soil formed on the younger "upper" till (Site 1).

TABLE 1. SUMMARY OF PRINCIPAL CHARACTERISTICS OF UPPER AND LOWER TILL(1)

	Upper till	Lower till
Distribution:	Found throughout the uplands and in parts of the valley as a discontinuous veneer over bedrock or lower till.	Usually found only in areas of thick till, both in the valley and in the uplands
Thickness:	Nowhere observed to be greater than about 8 feet thick.	Known to be 70 feet thick in some areas. Probably greater than 100 feet thick in some drumlins.
Nature of contact between upper and lower till:	Sharp, except where lower till is overlain by a particularly fine-grained upper till, in which case the contact is apparently gradational. Structural deformation of the contact was not observed.	
	Percent	Percent
Texture:	Gravel: 11 - 31 Sand: 40 - 68 Silt: 10 - 35 Clay: 1 - 9	Gravel: 8 - 17 Sand: 31 - 55 Silt: 23 - 42 Clay: 7 - 18
	(all material finer than -4ϕ; 10 samples upper till, 9 samples lower till).	
	Generally loose and incoherent; texture controlled by lithology of local bedrock.	Generally very compact and coherent. No obvious relationship between texture and lithology of local bedrock.
Jointing:	Rare: Found only in some exposures of the fine-grained facies west of the fault. Poorly developed subvertical joints and subhorizontal partings present.	Common: Best-developed in weathered zone. Subhorizontal joints generally an inch to a few inches apart and, where closely spaced, impart a fissility to the till. Subvertical joints generally a few inches to a foot apart.

TABLE 1 (Continued). SUMMARY OF PRINCIPAL CHARACTERISTICS OF UPPER AND LOWER TILL[1]

	Upper till	Lower till
Weathering:	Generally to a depth of less than 3 feet. Till west of the border fault may show a weathering profile somewhat thicker than 3 feet and rarely exhibit dark brown staining around clasts and along joints. Contact with the unweathered till is usually distinct but gradational.	Weathered to a depth of 15 feet in some areas. Dark brown (7.5 yr 3/2, damp) staining is common along joints and on clasts in this zone. Contact with unweathered till is sharp.
Color of Matrix: (Munsell, 1954; damp)	Olive gray to olive 5Y4-5/2-4 (unweathered).	Olive gray to olive 5Y4-5/2-3 (weathered); dark gray to gray 5Y4-5/1 (unweathered).
Landforms:	None. Generally as a veneer reflecting the morphology of underlying lower till or bedrock.	Constitutes the bulk of material in drumlins. May underlie the smooth lower slopes of hills.
Origin:	Bulk of material apparently derived from unweathered local bedrock.	Coarse fraction apparently derived largely from unweathered local bedrock. Matrix may have been derived largely from mantle of highly weathered bedrock.
Age:	Late Wisconsin. Deposited about 20,000 years B.P. (Schafer and Hartshorn, 1965).	Early Wisconsin. Deposited before 38,000 years B.P. (Schafer and Hartshorn, 1965).

1. From Campbell, 1974.

CHAPTER II

MATERIALS AND METHODS

Soil Sampling

Soils from six sites in the state were described and sampled for analysis. The soils are representative of well-drained soils that develop on till in the state. Figure 1 shows their distribution in Massachusetts. Profile descriptions were made for the soil at each site. The soil and till were sampled with a garden spade in a 1x1 meter pit. Where road cuts or borrow pits were sampled, the face was cut back a minimum of .5 meters. Care was taken to collect a representative sample and, therefore, a sample for any particular horizon consisted of sub-samples taken along at least 1 meter in a horizontal plane. Approximately 10 Kg. bag samples were taken for each horizon.

Four of the soils sampled are well drained soils of the Paxton series, one of the more common New England upland soils developed on compact tills. The Merrimac soil, sampled at site 2, is developed on a thin outwash deposit over a flow till (Hartshorn, 1967). It is included to provide a contrast with the clay mineral weathering sequence in the till soils. The Broadbrook soil sampled at site 1 is also well-drained but is developed on a silt loam or

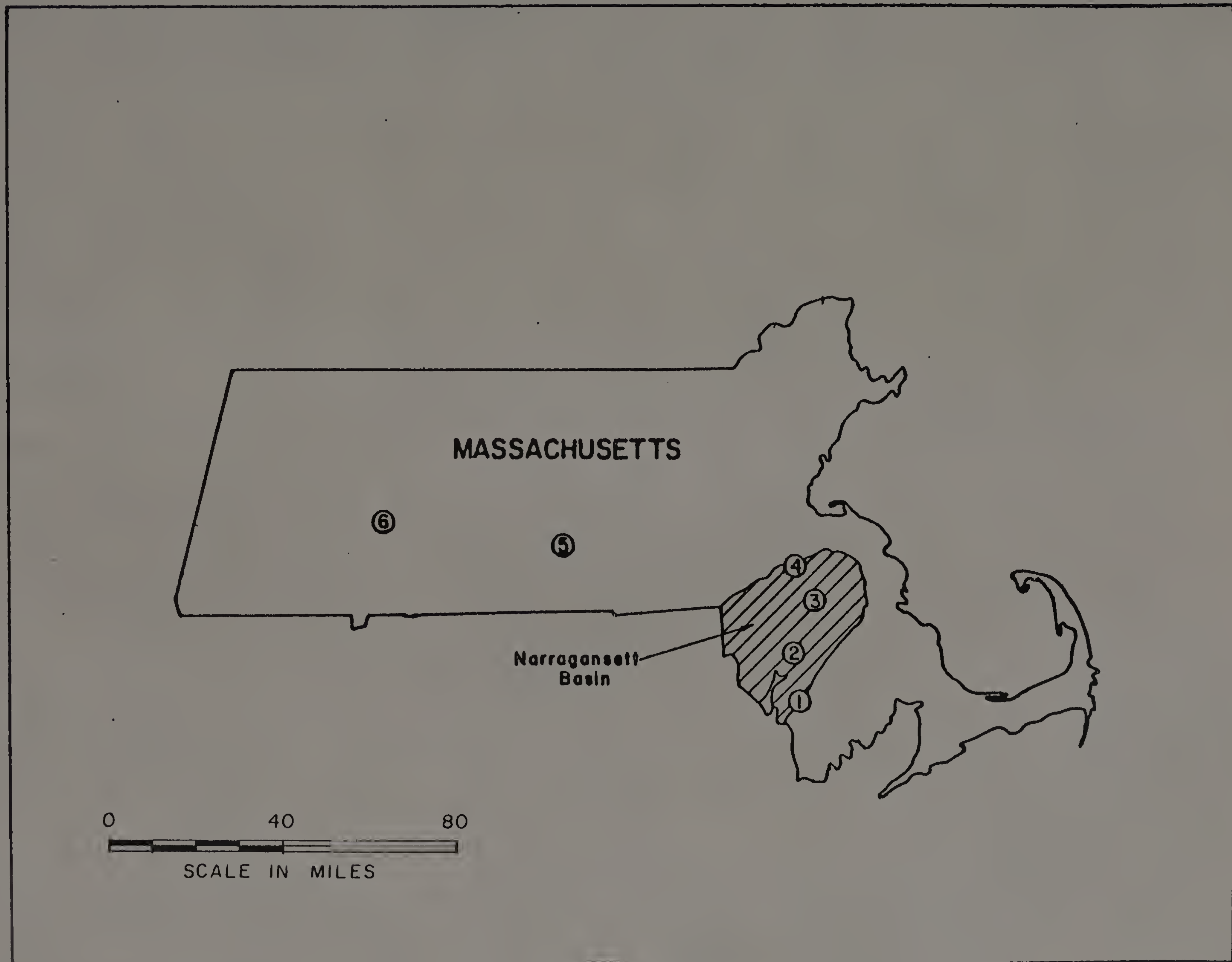

FIG. 1. MAP OF MASSACHUSETTS SHOWING STUDY SITE LOCATIONS

very fine sandy loam compact till. Complete series descriptions are provided in the appendix.

X-ray Diffraction

X-ray diffraction was done on the less than 2 um fraction on a G.E. XRD-5 diffractometer equipped with a Cu-target X-ray tube, Ni K-beta filter, and a proportional counter. Scans were made at 2 degrees/min. with medium resolution collimators and a 2 degree receiving slit. Clay mounts were prepared on ceramic plates by sedimentation in a centrifuge or by a suction apparatus similar to that described by Kinter and Diamond (1956). Diffraction patterns were run on mounts that had been Na saturated, air dried; Mg saturated, glycerol solvated; K saturated and heated consecutively to 200^{o}, 350^{o}, and $525^{o}C$. K saturated samples were initially heated to $200^{o}C$ and allowed to equilibrate in the air overnight. Heating at this low temperature encourages collapse of any low charge vermiculites (Edward Perry, pers. comm., 1976). Separation of the clay fraction was accomplished without iron oxide removal or other pretreatment. Pretreatments were avoided so that mineralogical analysis would reflect the properties of the clay fraction as it is in the field. It is believed that Fe removal may affect interlayer material and alter the behavior of 14A minerals. Dispersion was accomplished by successive agitation (mixing) in a Waring blender and, in some cases, by sonification. Na saturation facilitated dispersal in some cases and was used as a reference to compare K saturated samples. A series of diffraction patterns for any particular sample are of the same mount, as cation saturation was done after the mount was prepared on a porous plate. The appropriate chloride salt solutions were leached through mounts on the suction apparatus to provide the proper saturating cations. Glycerol solvated samples were prepared by leaching Mg saturated mounts with a 10% glycerol solution in ethanol. The mounts were immediately placed in a 100% glycerol atmosphere in a desiccator and the desiccator heated overnight at 40°C in an oven. To check the reliability of this method, clay standards were treated in this manner and diffraction patterns made.

A vermiculite clay from Wards Scientific was prepared as above. From the Na saturated sample, (pattern not included) it appears the Wards sample is a random ordered mixed-layered vermiculite/illite. With K saturation, complete collapse is indicated, supporting the velidity of the saturation method. A smectite standard treated with Mg saturation and glycerol solvation also behaved predictably.

Citrate Extraction Experiment

The Broadbrook soil at site 1 and the Paxton soil at site 6 were selected for the extraction study. These represent soil development on the upper and lower tills. Inter layers were removed according to the method of Tamura (1958). Known quantities of the less than 2 um fraction were boiled in 1N Na citrate for 9 hours. The citrate solution was renewed hourly and each hourly solution was carefully decanted and saved for subsequent analysis of dissolved Al and Fe. CEC was determined on sub-samples of each clay before the experiment and after 3, 6, and 9 hours of extraction. Al was determined by the Aluminon method (Hsu, 1963) and Fe by O-Phenanthrolein. CEC was determined after a method described by Jackson (1974), for both Ca and K exchange.

Comparison of XRD patterns of extracted samples with those previous to the treatment allowed for more detailed interpretations of observed reflections. These interpretations allowed criteria to be developed which were then used in identifying clay minerals in the soils from the remaining sites.

Criteria for Identification of Clay Minerals and Estimation of Relative Abundance

Due to the complexity of interpreting the diffraction patterns, criteria were established to provide consistency. Difficulty was encountered in two respects. When both chlorite and "chloritized" vermiculite (Sawhney, 1960) occur in the same sample the distinction is difficult without removing interlayers. Second, the second order vermiculite and chlorite peak at 7.15 masks the (001) of the kaolinite peak. The DMSO method (Gonzalez and Sanchez, 1968) was not attempted, so it is not known if such a procedure could have identified kaolinite in these soils. It is believed, however, that kaolinite is not an important constituent of the clay fraction.

"Chloritized" vermiculite was identified by a 14A peak that would not collapse following K saturation and heating to 200 C. It could be distinguished from chlorite in two ways. The 14A peak disappears following heating to 525 or 550°C if the mineral is chloritized vermiculite but will shift to 13.6 - 13.8 if there is chlorite present. Secondly, if both are present the (002) at 7.15 A in a sample heated to 200°C will be much weaker if chloritized vermiculite is predominant. In a chlorite-rich sample, a second order peak more intense than the (001) is consistent with the presence of an Fe-rich metamorphic chlorite.

Gibbsite was identified by the presence of a peak around 4.85A. In most cases this peak was distinct and not easily confused with the (003) of the 14A at 4.74 A. A secondary criterion was the disappearance of the 4.85 A peak following heating to 350°C.

The presence of the mixed-layered illite/vermiculite was identified by the occurrence of peaks at 12.0A - 12.5A and 3.45A in a Na saturated-air dried sample. Additional conclusions about its characteristics were made based on observations of peak shifts following K saturation before and after Na citrate extraction of the Paxton soil sampled at site 6.

The relative abundance of any mineral was estimated by the peak intensity ratio of the first and second order reflections. In the case where both vermiculite and chlorite contribute to the intensity of the 14.2A peak, a judgement was made based on the intensity of the chlorite peak following heating to 525^{o}C.

Particle-Size Analysis

The less than -2ø fraction of the soils and tills was analyzed for particle-size distribution after a method developed by Kerry Campbell, James Mulholland, and Robert Newton, all formerly of the Departments of Geology and Geography at the University of Massachusetts. The method is adapted from the ASTM (1972) and incorporates procedures found useful from experience with tills in New England. The procedure is explained in detail by Mulholland (1974) and summarized in the Appendix. Computation of testing results was done by computer, using APL language and a program written specifically for this procedure.

CHAPTER III

RESULTS AND DISCUSSION

Table 2 summarizes soil characteristics at each sampling point, identifies the horizon sampled, and presents the results of the particle-size analysis of selected horizons. Complete profile descriptions are included in the Appendix. All the soils are well drained and are classified as Typic Fragiochrepts soils, with the exception of the Merrimac soil at site 2.

The profiles sampled in the eastern portion of the state, with the exception of the soil at site 3, show an unconformity between the B and C horizons. This apparent unconformity was identified either by the contrasting texture and color of the A and B horizons with that of the C horizon, or by the characteristic occurrence of significant amounts of well sorted sand in the solum. These soils seem to be developed in a mixture of underlying till material and eolian sand and silt deposited during wind action associated with the retreat of the Laurentide ice sheet. Figure 2 is a scanning electron micrograph of a quartz grain taken from the B horizon of the Broadbrook soil at site 1. The rounded shape of the grain and upturned plates covering most of the grain surface indicate deposition within an eolian environment. SEM investiga-

TABLE 2. SOIL DESCRIPTION, HORIZONS SAMPLED AND PARTICLE-SIZE DATA

Site	Series name	Classification	Till unit	Horizons sampled	Depth Cm.	Depth In.	Texture[1] % sand	Silt	Clay
1	Broadbrook	Typic fragiochrepts	Upper	A_p	0-20	0-8			
				B_{21}	20-46	8-18	54	39	7
				B_{22}	46-76	18-30	54	39	7
				IIC_x	76+	30+	48	46	6
2	Merrimac	Typic dystrochrepts		A1 + A2	0-76	0-3			
				B_{21}	7.6-46	3-18	76	19	5
				B_{22}	46-68.6	18-27			
				IIC	68.6-190.5	27-75			
				$IIIC_x$	109.5+	75+	56	31	13
3	Paxton	Typic fragiochrepts	Upper	A_p	0-20	0-8			
				B_{21}	20-40.6	8-16			
				B_{22}	40.6-61	16-24	67	30	3
				C_x	61+	24+	68	27	5
4	Paxton	Typic fragiochrepts	Upper	A_1 + A_2	0-5	0-2			
				A_3	5-10	2-4			
				B_{21}	10-40.6	4-16			
				B_{22}	40.6-61	16-24	63	33	4
				IIC	61-76	24-30	61	32	7
5	Paxton	Typic fragiochrepts	Lower	A_1	0-13	0-5			
				B_{21}	13-30.5	5-12	60	33	7
				B_{22}	30.5-48	12-19	60	32	8
				B_{23}	48-58	19-23			
				B_3	58-74	23-29			
				C_x	74+	29+	63	28	9
6	Paxton	Typic fragiochrepts	Lower	A_p	0-20	0-8			
				B_{21}	20-61	8-24			
				B_{22}	61-86	24-34	70	22	8
				C_x	86+	34+	78	16	6

1. USDA textural classification.

Fig. 2 Scanning electron microscope photograph of a quartz sand grain taken from an eolian mantle (110X). Note the rounded shape of the grain and the upturned plates covering most of the grain surface. Sample collected from the B22 horizon at Site 1.


100.0 u
11-1 20.0 14 222 405

tions of this and other soils in the area (Peter Fletcher, pers. comm., 1978) indicate an eolian origin for some of the sand fraction of the A and B horizons. For a complete discussion of SEM analysis of quartz grains, the reader is referred to Krinsely and Doornkamp (1973). The presence of a wildblown component in these soils is consistent with the findings of Colby, Light, and Bertinuson (1955), and with profile descriptions of many soils mapped by the Soil Conservation Service in this area.

Mineralogy and Weathering of Lower Till Soils

The mineralogy and weathering sequence in soils developed on lower till is represented by XRD patterns for the Paxton soil at site 6 (Figure 3). The large unmarked peaks in these and other XRD patterns are quartz and feldspar reflections from the ceramic plate. Orientation of clay minerals when prepared in a thin mount was found to be superior to thicker mounts. A thin clay mount also allowed for easier and more reliable cation saturation.

In Figure 3, the peaks at 14A and 7.15A correspond to the (001) and (002) of discrete chlorite, although some of the intensity of the 14A peak may be due to chloritized vermiculite. The peak at 12A is likely the (002) of a mixed-layered 14/10 mineral, however, the superlattice peak at 24A is not evident.

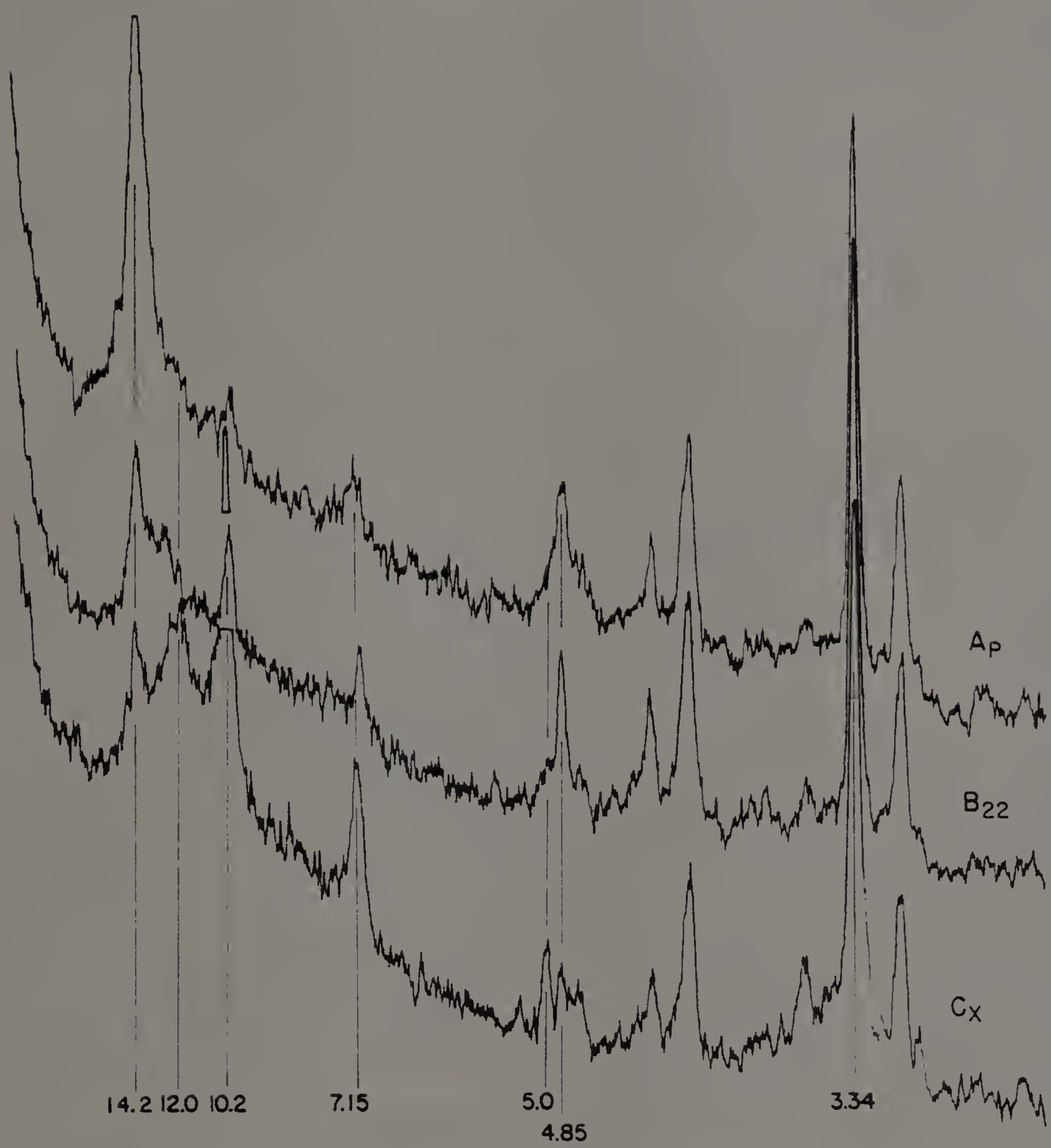

FIG. 3 X-RAY DIFFRACTION PATTERN FOR THE PAXTON SOIL AT SITE 6 FOLLOWING SODIUM SATURATION AND AIR DRYING.

The peaks at 10.2A and 5.0A correspond to the (001) and (002) of illite. The peak at 12.0A and the illite peaks at 10A and 5A decrease while the 14A peak increases in intensity toward the surface indicating the weathering of discrete illite and illite layers in the mixed-layered mineral to a 14A mineral, possibly chloritized vermiculite.

As seen in Figure 3, a peak at 4.85A is present in all three horizons. It is believed that the peak represents a gibbsite reflection. Figure 4 is a diffraction pattern of the C horizon of an additional soil sampled in southeastern Massachusetts but not studied in this paper. It is included here because gibbsite is found to be a significant component of its clay mineralogy.

This soil is developed in a 6-foot thick eolian deposit of loamy medium to fine sand over an upper till. Figure 4 shows the gibbsite peak at 4.85A to be as intense as the 14A peak. The peak at 4.36A in this pattern is a secondary gibbsite peak. In soils studied in this thesis, the gibbsite peaks are not as strong but still distinct.

The XRD patterns of clay samples from the profile of the Paxton soil at site 6 before and after citrate extraction to remove interlayers, are represented in Figure 5. A comparison of the patterns before extraction with those in Figure 3 shows that K saturation causes a small decrease in intensity of the 14A peaks and corresponding increase of

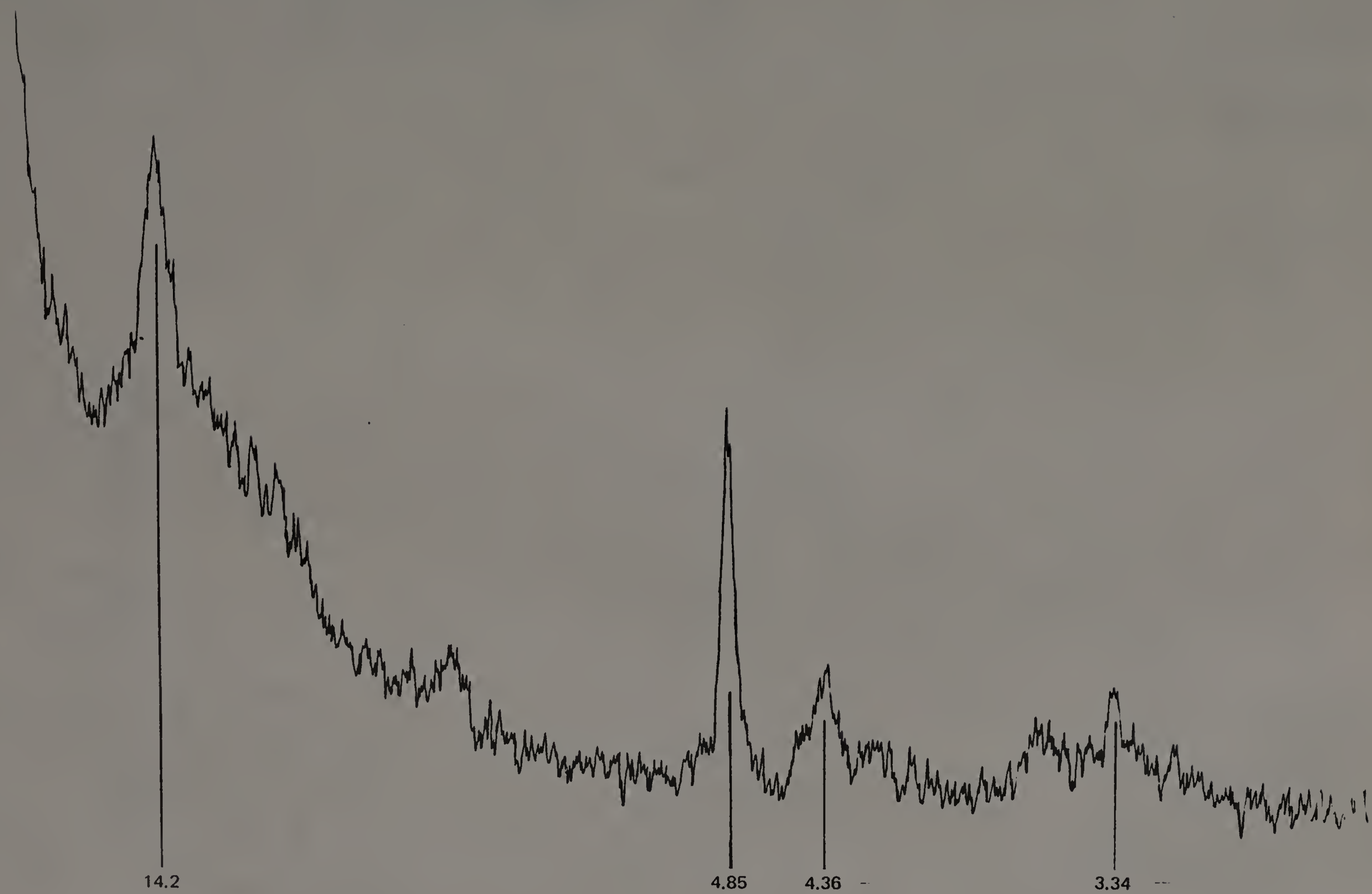

FIG. 4 X-RAY DIFFRACTION PATTERN FOR A SOUTHEASTERN MASSACHUSETTS SOIL SHOWING WELL DEFINED GIBBSITE PEAKS

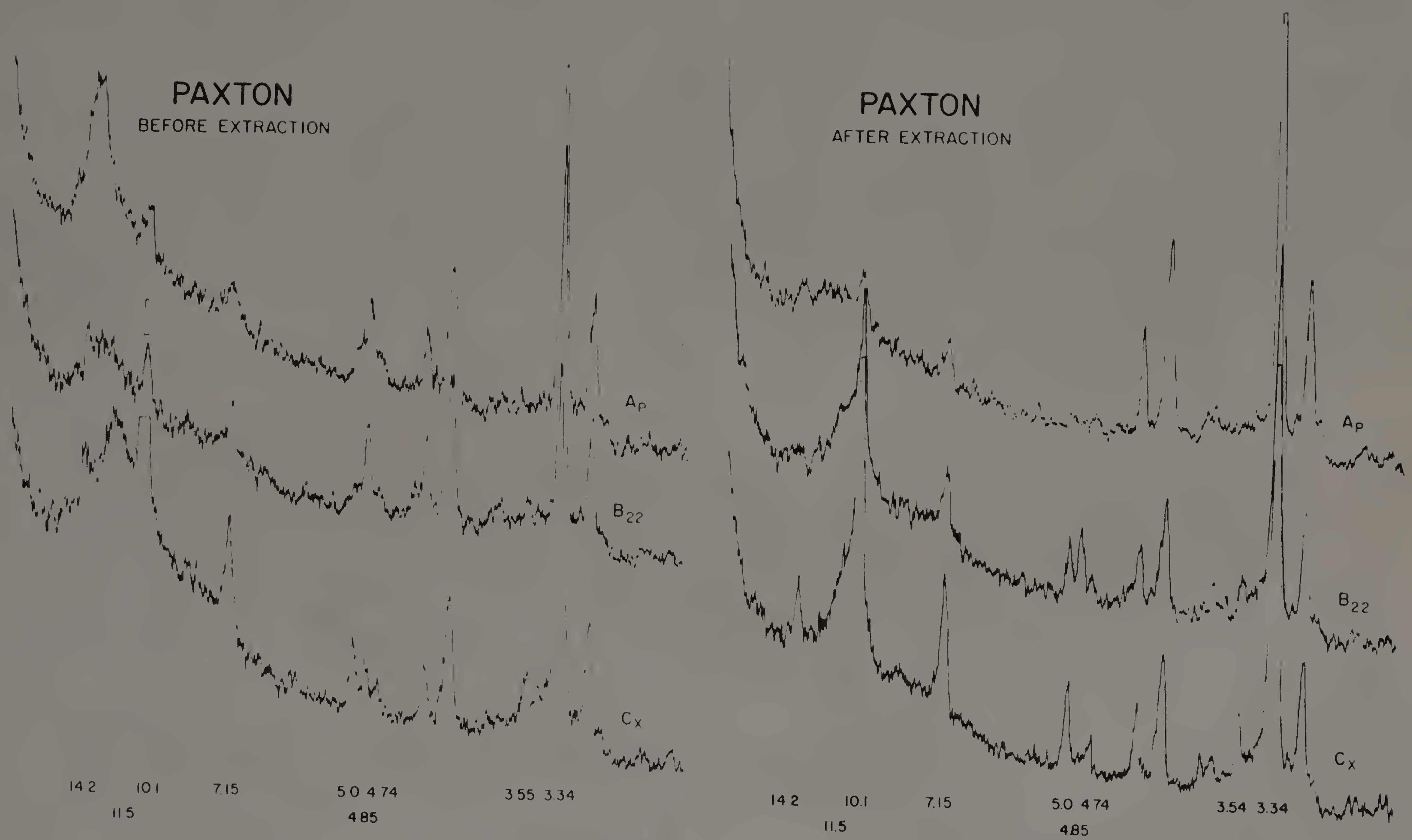

FIG. 5 X-RAY DIFFRACTION PATTERNS FOR THE PAXTON SOIL AT SITE 6 FOLLOWING POTASSIUM SATURATION AND HEATING TO 200°C, BEFORE AND AFTER A 9-HOUR EXTRACTION WITH SODIUM CITRATE.

the 10A peaks. This indicates that some 14A spacings are unoccupied by interlayers, adsorb K and collapse, providing evidence for the occurrence of discrete vermiculite in each horizon. However, a portion of the increase in the 10A peak intensity may be due to collapse of vermiculite layers in the mixed-layered mineral.

According to Jackson's (1963) anti-gibbsite hypothesis, discrete gibbsite should not form in the soil if there are available vermiculite interlayer spaces. Jackson proposes that vermiculite interlayer spaces serve as sinks for available Al and prevent gibbsite from precipitating until all the spaces are filled or blocked. Thus, the presence of gibbsite suggests that interlayer spaces should be saturated with Al-hydroxy. However, the fact that gibbsite is precipitating in soils that contain some collapsible vermiculite indicates that the anti-gibbsite effect may not be 100% operable in these soils.

The occurrence of a mixed-layered 10/14A mineral in lower till soils has been reported by Krohelski (1976). Newton (1978) also reports the occurrence of a mixed-layered 10/14A mineral he termed "illite/vermiculite" in weathered sections of the lower till. In some weathered sections of the till, he reports that "vermiculite" layers do not collapse when K saturated.

Newton (1978) sampled upper and lower tills in Massachusetts, New Hampshire and Connecticut. In the lower tills, he has identified four different weathering zones that occur in a certain sequence, each with a distinct mineralogy. The upper zone (zone 1) is characterized by the presence of a mixed-layered "illite/vermiculite" that does not collapse when K saturated. The zone below (zone 2) contains "illite/vermiculite" that does collapse. The next lower zone in the sequence (zone 3) does not contain a mixed-layered mineral but only discrete collapsible vermiculite. The bottom of this zone and the top of zone 4 corresponds to the contact between the oxidized and unoxidized zones described previously. Zone 4 contains only the parent clay minerals, illite and chlorite. Newton uses this and other data to support his hypothesis that the lower till is a till of considerable age. He tentatively dates the till as older than early Wisconsinan but probably younger than Illinoian.

To explain why K saturation did not cause collapse of interlayer spaces in the "illite/vermiculite", Newton (1978) initially proposed Fe hydroxy as the interlayer material but found multiple Na citrate-dithionite extractions ineffective in obtaining collapse. His second hypothesis involves the structural charge in the clay lattice. He reasoned that oxidation of structural Fe during weathering would result in a lower net negative charge in the 2:1 layers. If the negative charge were low enough, K could not impose a strong enough attraction to collapse the interlayers. He proposed a weathering scheme that progresses through two stages. Initially, a mixed-layer illite/vermiculite forms from illite through the loss of K. In the second stage, octahedral Fe is oxidized reducing the net structural charge of the vermiculite. The next stage, which Newton (1978) did not observe, would be the further lowering of structural charge and the formation of a smectite.

The patterns in Figure 5 seem to be consistent with Newton's observations, although data in this study do not support his hypothesis regarding the nature of the mixed-layered mineral. As seen in Figure 5, after Na citrate treatment and K saturation of the clays, the intensity of the 14A peaks decreased, the 12A peak disappeared and the intensity of the 10A peak increased. This indicates that sodium citrate removed interlayers permitting 14A spacings to collapse to a 10A -10A sequence upon K saturation and drying.

Why Newton's extraction technique did not remove interlayers is unclear, but it should be noted that site 6 is exactly where he sampled a lower till for his study. The Paxton soil at this study was sampled directly above the face where Newton obtained his till samples, therefore, minerological differences should not contribute to the discrepancy.

Formation of the mixed-layer mineral may have occurred in an earlier weathering period and the mineral may not currently be forming in the C horizons of lower till soils. Indeed, the data contained in Figure 3 suggest this to be the case. The relative amount of the mixed-layered mineral is less in the B than C horizon and it is totally absent in the A horizon.

It was also observed in this study that the mixed-layered mineral was not entirely "chloritized" in the C horizons. Figure 6 shows the results of various treatments on the C horizon from the two lower till soils. The peaks at 12A and 3.45A correspond to the (002) and (007) of the mixed-layered mineral. When these soils are K saturated, these peaks shift toward a lower spacing. The soil from site 5 shows this shift more clearly. The (002) shifts from 12.2A to 11.5A and the (007) from 3.45A to around 3.40A, a significant shift at this angle. The mineral therefore can be described as a illite/choritized vermiculite in which most, but not all, of the 14A spacings contain interlayer material, probably Al hydroxy. The fact that the (007) is visible suggests a certain amount of regular ordering. In this case, the formation of a 14A - 10A - 14A sequence results in a superlattice of 24A spacings. The lower orders

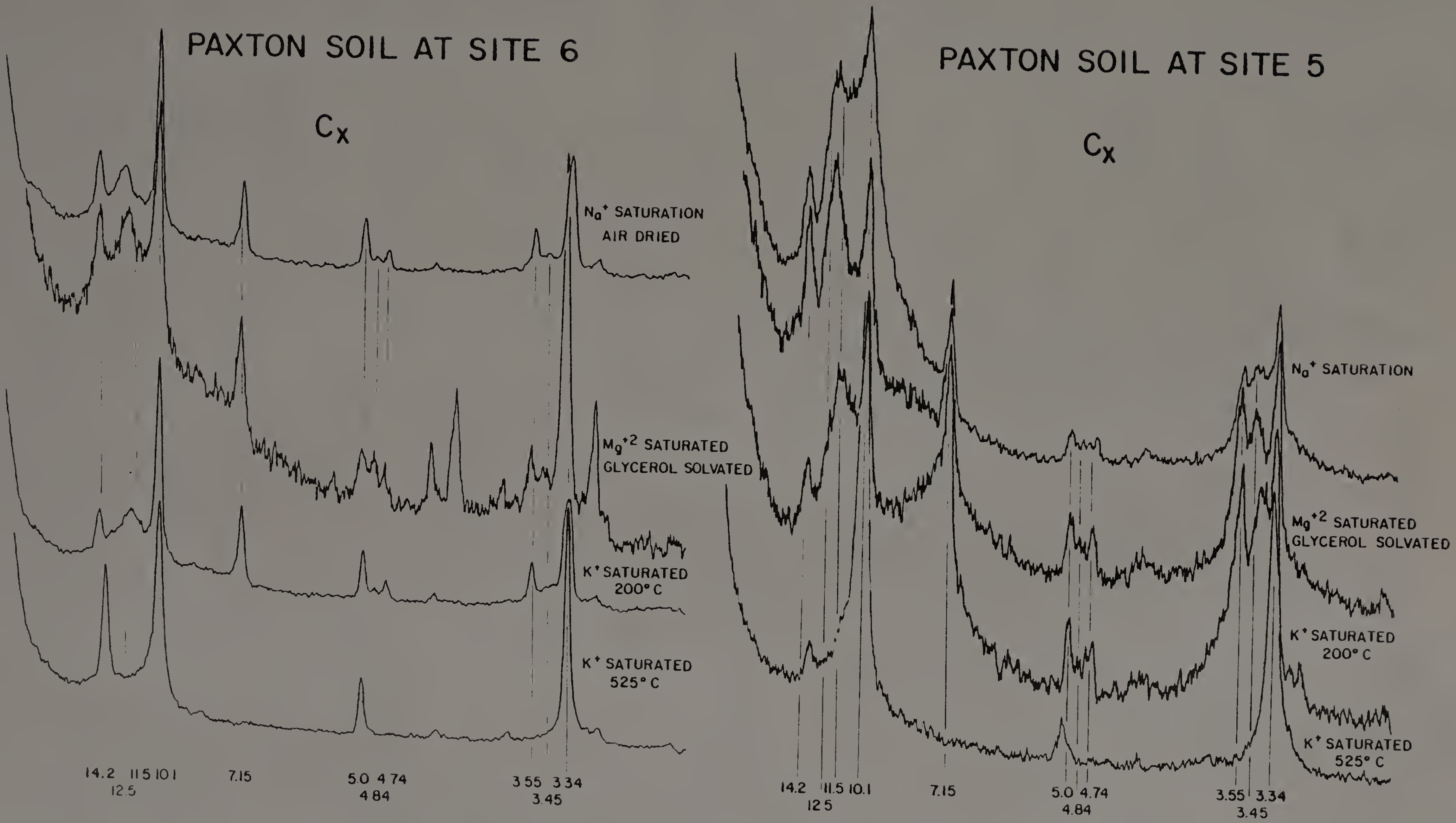

FIG. 6 X-RAY DIFFRACTION PATTERNS OF THE Cx HORIZON FROM TWO PAXTON SOILS.

would be a (002) at 12A, a (003) at 8A, a (004) at 6A and so on to the (007) at around 3.43A. The presence of the (002) near 12A and the (007) near 3.43A confirms the sequence stated above. This type of regular ordering is known as the allevardite type (Brindley, 1956). The patterns of samples heated to 525°C indicate that detrital chlorite is also present in significant amounts in the Paxton soil at site 6.

Since the weathered zones of the lower till represent a paleosol, it is uncertain when Al interlayers were formed and how they might affect the further weathering of clay minerals. It is probably safe to assume that Al hydroxy interlayers are in a somewhat stable condition in the solum. Therefore, the weathering occurring at present involves further stripping of K from residual illite and the subsequent hydration and chloritization of new 14A spacings. The fact that the lower till contains a paleosol horizon may indicate that the Al interlayers and gibbsite present in the C horizons of lower till soils are remnants of an earlier period of weathering. Newton's (1978) bulk chemistry data for the clay fraction show that Al enrichment exists as deep as 5.8 m in the lower tills. Therefore, Al may have been available to occupy interlayer spaces during an earlier interglacial or interstadial age. He also reports Al enrichment to a depth of 8.2 m for an upper till in Connecticut. However, since he found only collapsible vermiculite, illite and chlorite in the section, it appears that Al enrichment (with K, Si and Mg depletion) precedes the development of Al hydroxy interlayers and cannot be used as an indicator for the chloritization process.

As seen in Figure 3, the 4.85A peak of gibbsite is present in all three horizons but increases in intensity near the surface. This probably indicates that gibbsite is forming in this soil. The increase in intensity of the gibbsite peak toward the surface appears characteristic of each profile sampled in both lower and upper tills.

Mineralogy and Weathering of Upper Till Soils

Figure 7 shows XRD patterns for Na saturated clays from the Broadbrook soil which is representative of the upper till soils sampled. The peaks evident in the Cx horizon at 14.2A, 7.15A, 4.7A, 3.54A and 10.2A, 5A, 3.34A represent the (001), (002), (003) and (004) of chlorite and the (001), (002) and (003) of illite, respectively. Most of the intensity of the (003) of illite, however, can be attributed to quartz. Patterns run following heating to 525°C (not shown) confirm the presence of chlorite in the Cx. Thus, only parent clay minerals seem to occur in this horizon.

In the B_{22} horizon, the clay mineralogy is very different from that of the Cx horizon. As evidenced by the tremendous decrease in the intensity of the 10A peak, illite

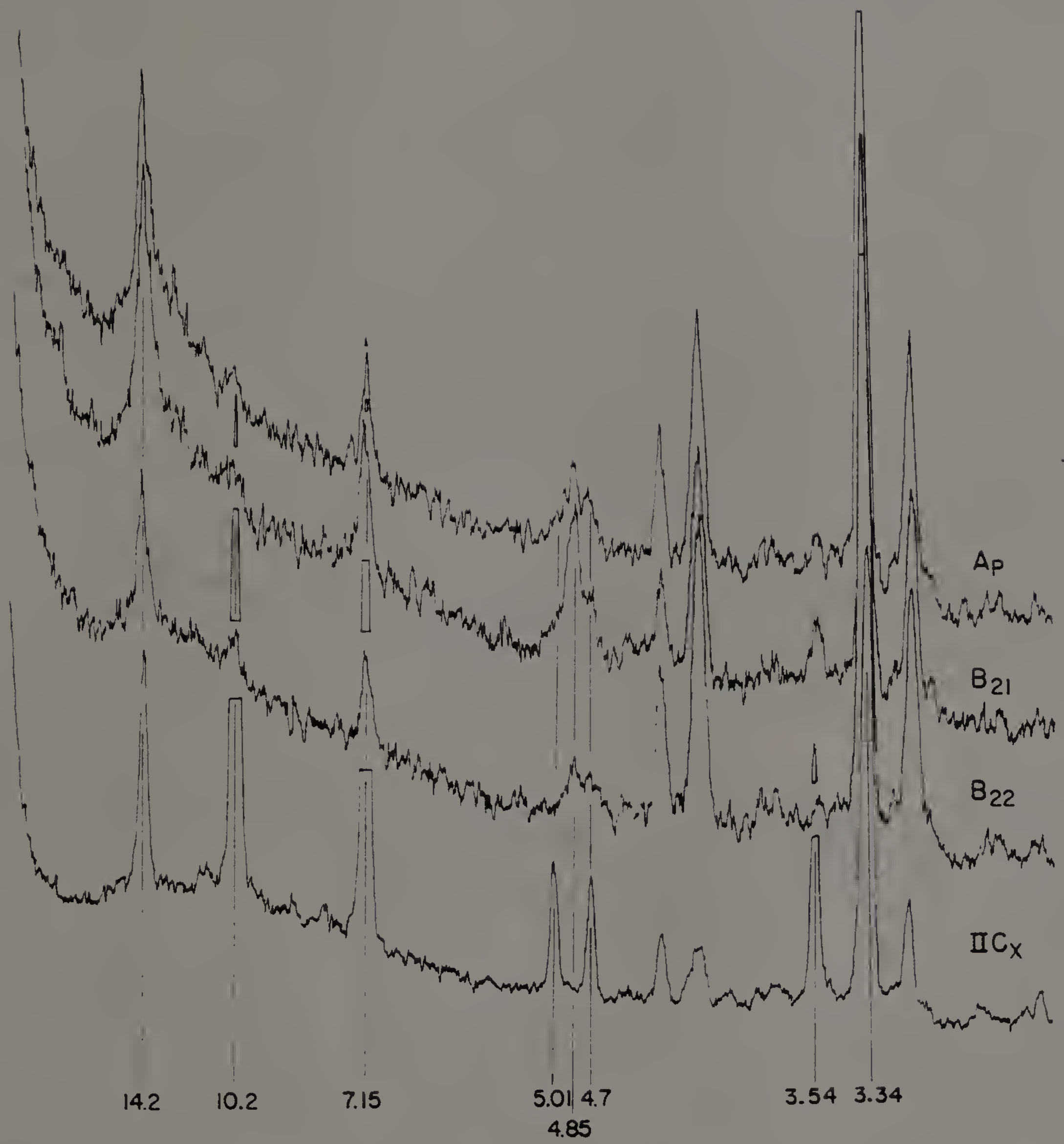

FIG. 7 X-RAY DIFFRACTION PATTERNS FOR THE BROADBROOK SOIL AT SITE 1 FOLLOWING SODIUM SATURATION AND AIR DRYING.

has been almost completely weathered. The apparent weathering of chlorite is shown by a significant decrease of its (002) and (004) at 7.14A and 3.35A in Figure 7. Figure 8 shows the effects of K saturation before and after the Na citrate extractions. The fact that K saturation does not cause collapse previous to Na citrate extraction indicates the presence of vermiculite with interlayers. When these samples are heated to 525°C (not shown) the (001) of the chlorite peak persists, confirming the presence of residual chlorite. Thus, the 14A peaks in the A and B horizons are due to chloritized vermiculite and some residual chlorite.

XRD patterns in Figure 8 show shoulders on the 10A peaks between 11A and 12A. Patterns on the right represent samples after interlayer removal and K saturation. The shoulders may result from collapse of vermiculite layers within the chlorite crystals. Since the shoulders only appear after Na citrate treatments, it is likely the vermiculite layers were originally occupied or blocked by interlayer material. The sequence proposed would be chlorite/chloritized vermiculite/chlorite. Because no distinct peaks are evident, the interstratification is probably randomly distributed within each chlorite crystal. This hypothesis assumes that the Na-citrate treatment extracted all Al hydroxy interlayers. An alternate explanation is that Al removal is incomplete and that the interlayering results from illite/chloritized vermiculite.

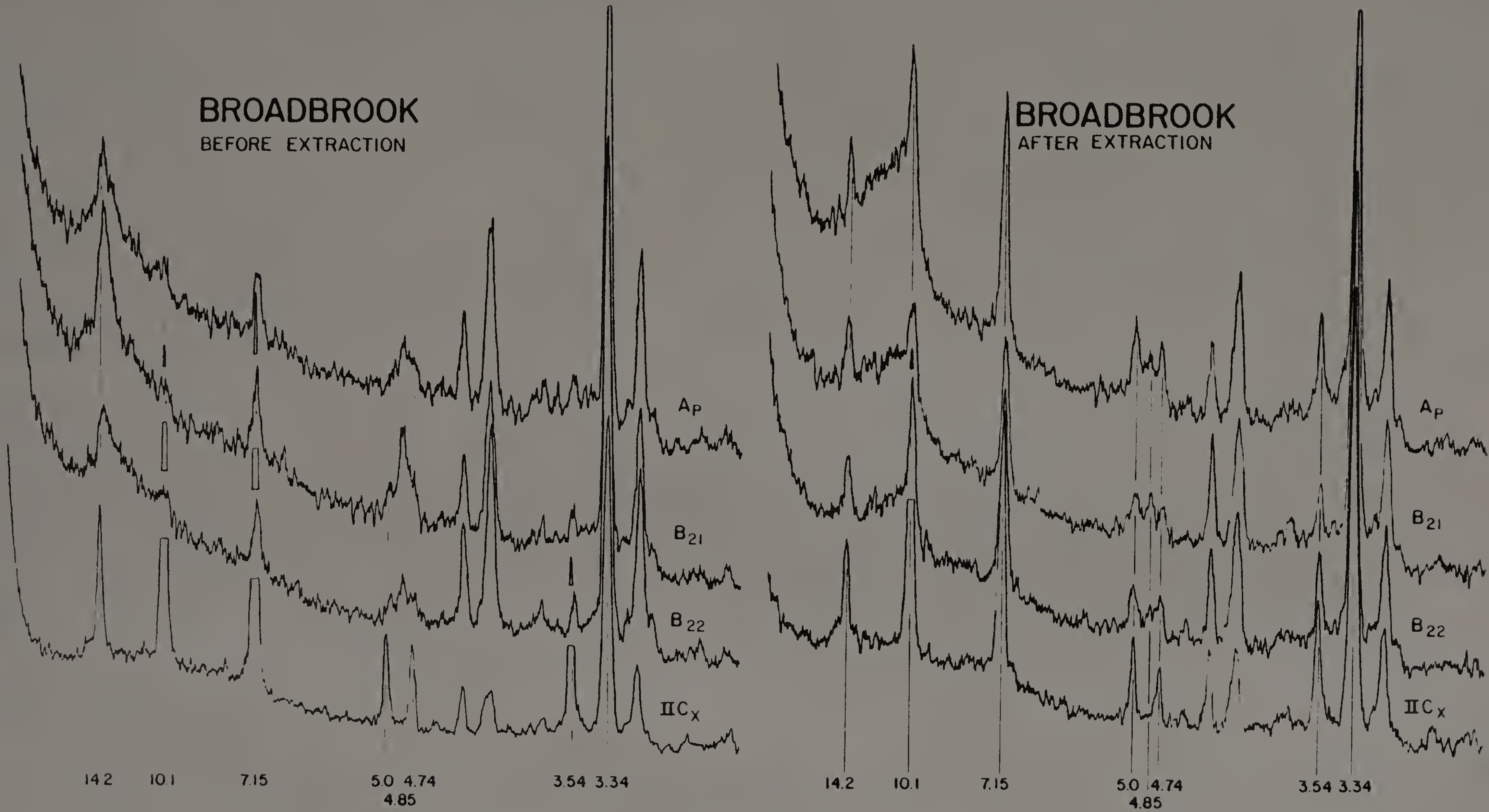

FIG. 8 X-RAY DIFFRACTION PATTERNS FOR THE BROADBROOK SOIL FOLLOWING POTASSIUM SATURATION AND HEATING TO 200°C, BEFORE AND AFTER A 9-HOUR EXTRACTION WITH SODIUM CITRATE.

Illite would have to have been the parent clay mineral for this arrangement.

Al removal from this soil seems to yield more distinct diffraction patterns. When Al is removed, the (002) and (004) of the chlorite at 7.14A and 3.53A increase in intensity (Figure 8). The ratio between the intensities of the (001), (002) and (004) of chlorite is fairly consistent throughout the profile after interlayers are removed.

The presence of chlorite in a near-surface environment is curious due to its known susceptibility to weathering (Droste, 1958). Mg-chlorite is certainly more suspectable to weathering than illite. There are a number of possible explanations for the observed data.

One involves the nature of the solum at this site. As the soil description and SEM work indicate, there is a eolian component in the soil. If unweathered chlorite were being deposited from a nearby source, its presence would be due to continual deposition and not its ability to withstand weathering. However, it seems unlikely that chlorite could remain in an unweathered state during erosion of the source area and transport to the site of deposition, for during that period it would be in a favorable environment for rapid alteration.

Another explanation involves the sorption of Al hydroxy at the edges of detrital chlorite crystals. In this model, octahedral Mg (or Fe) is rapidly stripped at exposed edges of the interlayers. The stripped areas, because of their increase in negative charge, tend to localize Al and facilitate the formation of amorphous Al hydroxy. Because the crystal edges are now blocked, further stripping of octahedral cations is slowed down. Frink (1965) has proposed that Al hydroxy may precipitate at vermiculite edges blocking, but not occupying, interior exchange sites. With time, the stripping front progresses toward the center of the crystal but at a much reduced rate. Eventually the crystal becomes "honeycombed" with Al hydroxy and unaltered brucite areas. This model may explain some observations made about chlorite in the A and B horizons at site 1.

As indicated, the higher order chlorite peaks at 7.15A (002) and 3.55A (004) are not visible until Al hydroxy was removed. After removal, peak intensities and peak ratios were almost identical in the weathered A and B horizons, to those in the unweathered C horizon. However, when the samples from the solum were heated to 525°C the resulting chlorite first order peaks were much weaker than that of C horizon chlorite. If the model outlined above is correct then chlorite from the solum might be expected to be less stable during heat treatments.

The increase in higher order peak intensities following Na citrate treatment can be explained by the fact that once

Al hydroxy is removed from edge areas, the scattering of x-ray particles is substantially reduced. This scattering due to interlayer amorphous Al may explain the absence of higher order reflections in a sample containing predominantly chloritized 14A material. The reduction of scattering would result in increased positive reinforcement of reflected beams such that the higher order reflections of chlorite would now be visible. Because much of the interlayer space remains occupied by the original brucite material, K saturation cannot effect collapse of chlorite crystals. However, instability observed during heat treatments indicates that the brucite layers are probably not continuous.

Gibbsite is present in the Broadbrook solum as indicated by the peaks at 4.85A in Figures 7 and 8. Since there is no hint of a gibbsite peak in the C horizons, it is concluded that gibbsite is a weathering product in the A and B horizons.

Na Citrate Extraction

Tables 3 and 4 present data from the Na citrate extraction. In the B horizons, Fe is removed at a high rate during the first hour and at a near constant rate for the remainder of the time. Fe is removed at a constant rate (10 to 16 meq/hour) from each C horizon throughout the extraction period. Al removal rates peak after five hours but are

TABLE 3. CEC AND Al and Fe IN SODIUM CITRATE EXTRACTS FROM <2 um SIZE FRACTION OF THE PAXTON SOIL AT SITE 6

Sample	Hour	meq/100g clay Al	Fe		CEC meq/100g Ca-Mg	K-NH4
				Initial -	16.4	7.3
Ap	1	141	20			
	2	234	10			
	3	347	12		17.5	
	4	618	11			
	5	919	20			
	6	800	5		21.0	6.8
	7	414	6			
	8	325	12			
	9	253	10		26.0	6.5
				Initial -	9.2	3.2
B_{22}	1	299	43			
	2	89	8			
	3	209	11			
	4	275	14			
	5	608	11			
	6	438	7		27.6	8.0
	7	141	4			
	8	75	3			
	9	294	16		31.7	9.8
				Initial -	8.6	2.3
Cx	1	243	20			
	2	248	8			
	3	442	13			
	4	377	13			
	5	576	6			
	6	428	4		22.6	9.5
	7	478	2			
	8	230	11			
	9	448	15		27.0	8.7

TABLE 4. CEC AND Al and Fe IN THE CITRATE EXTRACTS FROM <2 um SIZE FRACTION OF THE BROADBROOK SOIL AT SITE 1

Sample	Hour	meq/100g clay Al	meq/100g clay Fe		CEC meq/100g Ca-Mg	CEC meq/100g K-NH4
	0			Initial -	4.8	16
Ap	1	410	93			
	2	295	32			
	3	170	15		24.6	-
	4	258	13			
	5	605	9			
	6	205	11		27.0	10.5
	7	671	6			
	8	21	10			
	9	506	17		27.9	9.6
				Initial -	7.3	10.2
B21	1	279	106			
	2	379	30			
	3	190	15		21.9	12.4
	4	302	20			
	5	1345	16			
	6	358	8		30.0	-
	7	1027	4			
	8	51	8			
	9	152	13		34.5	11.0
				Initial -	9.3	6.8
B22	1	191	73			
	2	282	20			
	3	188	24		24.0	-
	4	376	12			
	5	613	12			
	6	181	6		24.2	8.6
	7	583	8			
	8	110	6			
	9	162	10		-	7.6
				Initial -	8.0	5.3
IICx	1	290	21			
	2	236	7			
	3	294	11			
	4	151	9			
	5	1218	14			
	6	333	3		6.9	4.2
	7	403	4			
	8	665	21			
	9	418	16		7.9	1.9

quite variable throughout the experiment. The data indicate that there is as much extractable Al in the C horizons as there is in the B horizons of both soils.

CEC data support the results of the diffraction study. Following extraction by sodium citrate, Ca-Mg CEC increases dramatically but $K-NH_4$ CEC changes little. This is consistent with the collapse of 14A spacings only after extraction. The CEC data also support the presence of vermiculite layers in the lower till soils. The K/NH_4 CEC before Na citrate treatments is only one-third to one-half that of the Ca/Mg CEC, indicating K fixation. In the Broadbrook soil there is little difference in the CEC's, which makes the occurrence of vermiculite in this soil more questionable.

Analyses of the citrate extracts provide no conclusive data regarding whether Al or Fe hydroxides are blocking the exchange sites. If either exists as atolls blocking the edges of vermiculite crystals, as suggested by Frink (1965), it may be impossible to correlate changes in CEC with the amount of Al or Fe extracted. The presence of gibbsite in these samples also confounds the interpretation.

Following Na citrate treatments, Ca-Mg CEC increases dramatically ($\pm$300 percent) in the Cx horizon of the lower till soil at site 6. The Broadbrook C horizon, however, showed little change. Again, this difference is consistent with the absence of available interlayer spaces before or after Na citrate treatments, and the presence of only illite and chlorite in the upper till.

Summary of Clay Mineralogy and Weathering Sequence

The summary of clay mineralogy is included in Table 5. Illite and chlorite are the primary minerals in the C horizons of every soil sampled. With proximity to the surface, these minerals decrease in abundance and chloritized 14A minerals become predominant. This sequence is consistent with the work of Sawhney (1960) in Connecticut. The absence of the lower order peaks of the 14A mineral in Figure 3 is consistent with the occurrence of chloritized vermiculite. It was observed during this study that whenever chloritized vermiculite was the dominant mineral in a sample, the (002) and (003) peaks would be all but absent.

Gibbsite is a common mineral in A and B horizons of each soil sampled and also is present in the C horizon of lower till soils.

Each soil sampled on lower till was found to be developed in the oxidized zone of that till. In lower till soils, the parent material is actually the upper surface of a paleosol, probably older than early Wisconsian. The parent clays in the C horizon of lower till soils are illite, chlorite and mixed-layered illite/chloritized vermiculite. Most, but not

TABLE 5. CLAY MINERALOGY SUMMARY

Site	Till unit	Series name	Horizon	Clay mineralogy					
				Ill	Chl	Ver	Gib	10/14	14/int.
1	Upper	Broadbrook	A_p	0	XX	0	X	0	XXX
			B_{21}	X	XX	X	X	0	XX
			B_{22}	X	XX	X	X	0	0
			IIC_x	XX	XX	0	0	0	0
2		Merrimac	$A_1 + A_2$	-	-	-	-	-	-
			B_{21}	X	X	X	X	0	XX
			B_{22}	XX	X	X	X	0	0
			IIC	-	-	-	-	-	-
			IIIC	XX	XX	X	0	0	0
3	Upper	Paxton	A_p	X	0	X	X	0	X
			B_{21}	-	-	-	-	-	-
			B_{22}	X	XX	0	0	0	XX
			C_x	XX	XXX	0	0	0	0
4	Upper	Paxton	$A_1 + A_2$	-	-	-	-	-	-
			A_3	0	0	0	XX	0	XXX
			B_{21}	-	-	-	-	-	-
			B_{22}	X	X	X	X	0	XXX
			IIC	XX	XX	0	0	0	0
5	Lower	Paxton	A_1	-	-	-	-	-	-
			B_{21}	-	-	-	-	-	-
			B_{22}	XX	X	X	X	X	XX
			B_{23}	-	-	-	-	-	-
			B_3	-	-	-	-	-	-
			C_x	XX	XX	X	X	XX	X

TABLE 5 (Continued). CLAY MINERALOGY SUMMARY

Site	Till unit	Series name	Horizon	Clay mineralogy					
				Ill	Chl	Ver	Gib	10/14	14/int.
6	Lower	Paxton	A_p	0	0	X	X	0	XXX
			B_{21}	-	-	-	-	-	-
			B_{22}	X	0	X	X	0	XX
			C_x	XXX	XX	X	X	XX	X

KEY:

0	Absent	Ill	Illite
X	Minor amount	Chl	Chlorite
XX	Significant amount	Ver	Vermiculite
XXX	Predominant	14/int.	Chloritized vermiculite
-	Not determined	Gib	Gibbsite
		10/14	Interlayered 10 and 14 angstrom mineral

all of the vermiculite spacings in the mixed-layered mineral contain interlayer Al hydroxy. Data here do not support Newton's (1978) hypotheses regarding the nature of the illite/vermiculite mineral. The oxidation of structural Fe and lowering of negative charge cannot account for the failure to collapse vermiculite layers. In this study, collapse of this and other chloritized minerals was obtained after 9 hour Na citrate extractions and K saturation. Na citrate extraction increased the Ca-Mg CEC 300 percent in the clay fraction of the C horizon in one lower till soil.

In lower till soils chlorite, illite and illite/chloritized vermiculite are being converted to chloritized vermiculite in the solum. Some of the mixed-layering can be observed in the B horizons but completely disappears in the A.

The illite/chloritized vermiculite interlayering is a regular ordering of 14A and 10A spacings of the allevardite type. Although the (001) superlattice peak was never observed, the higher order peaks at 12.2A (002) and 3.45A (007) were well defined and characteristic of the mineral.

The shift of the higher order peaks of illite/chloritized vermiculite to lower spacings following K saturation indicates that the mineral contains some collapsible layers previous to Na citrate extractions.

Only the parent minerals illite and chlorite are found in the C horizons of the upper till soils. The C horizons of these soils contain neither illite/chloritized vermiculite nor gibbsite as found in the C horizon of the lower till soils. The major clay mineral weathering reactions seem to be the conversion of illite, and some chlorite, to chloritized vermiculite, and the formation of gibbsite in the A and B horizons. Na citrate extractions have no effect on the Ca-Mg CEC in the C horizon of upper till soils.

The Merrimac soil that is developed on outwash, is identical in clay mineralogy to soils developed on upper till.

A soil chlorite sampled at one upper till site was found to be somewhat resistant to weathering processes in the solum. It is believed that this mineral is a partially weathered chlorite inherited from the underlying parent material. The recognition of the chlorite was not made until Al hydroxy had been removed with Na citrate treatments.

The solum of the two soils selected for detailed study have a similar weathering sequence, however, differences exist in the mineralogy of the parent materials. The presence of minor amounts of illite/chloritized vermiculite in the B horizon of the lower till soil (Paxton, site 6) is due to its development on a palesol. The conservative nature of chlorite in the upper till soil (Broadbrook, site 1) may be due to the relatively young age of the upper till and the protection of brucite layers by Al hydroxy. Ca-Mg CEC for both soils are almost identical both before and after Na citrate extractions except in the C horizons. Lower K/NH_4 CEC in the lower till soil before Na citrate treatments indicates fixation of K and the presence of some vermiculite.

The conversion of illite to vermiculite to chloritized vermiculite must involve a rapid chloritization step since vermiculite was found to be only a minor component of each soil and horizon sampled.

CHAPTER IV

CONCLUSIONS

In all profiles studied, chlorite and micas are weathering to vermiculite and chloritized vermiculite in the A and B horizons with weathering being more complete toward the surface horizons. Gibbsite is common in the solum of all profiles and present in the Cx horizons of the lower till soils. Chloritized vermiculite is also common in the Cx of these soils.

An interstratified mineral comprised of 10A (illite) and 14A (chloritized vermiculite) spacings is present in the B and C horizons of the lower till soils. The mineral is quite significant in upper sections of the Cx horizons but is less apparent in the B horizons. This interlayered mineral was never observed in the upper tills or the soils developed on these tills.

A degraded chlorite was observed in the A and B horizons of one upper till soil. The presence of chlorite in this soil may be related to the young age (15,000-16,000 years) of the till and the weathering phenomena presently occurring in the soil.

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APPENDIX

Grain Size Procedure

The following procedure is adapted from Royse (1970), and ASTM (1972), primarily for the analysis of glacial till. Great emphasis is put on the analysis of the clay size fraction; material larger than coarse sand is not included in the analysis. Dispersant concentration may not be sufficient for analysis of pure clay.

Grain size analysis for sand/silt/clay:

1) Mix sample with dispersant (Calgon: sodium hexametaphosphate at 2.55 gm/l) in blender.
2) Wet sieve sample with dispersant through 4 Ø (0.0625 mm) sieve; retain material passing sieve for hydrometer analysis; wash coarser material with distilled water.
3) Dry sieve material not passing 4 Ø sieve through sieve stack (0.5 Ø intervals; Ø sizes = $-\log_2$ diam. in mm); US Standard 5, 7, 10, 14, 18, 25, 35, 45, 60, 80, 120, 170, 230; for 25 minutes in RoTap shaker.
4) Add pan fraction to wet sieved material finer than 4 Ø.
5) Weigh sample retained on each sieve.
6) Mix total finer than 4 Ø fraction thoroughly with dispersant; fill settling tube to 1,000 ml calibration.
7) Hydrometer readings with buoyoucos hydrometer (gm/l) at 0.5, 1, 2, 4, 8, 15, 30, 60, 120, 240, 420, and 1440 minutes, taking control readings in dispersant each time.
8) Calculate cumulative percentages using corrected hydrometer readings (reading minus control) and sieve weights as input for SUPERMUD program.

SOIL PROFILE DESCRIPTIONS

Site:	1
Soil type:	Broadbrook stony fine sandy loam
Classification:	Typic Fragiochrepts
Location:	Bristol County, Massachusetts. City of Fall River. Borrow Pit east side of North Main Street 1/2 mile south of airport.
Vegetation and land use:	Young birches, briars and grasses. Old field.
Slope:	10 percent west
Physiography:	Side of hill
Parent material:	Gray silty upper till

Horizon	Depth cm/in.	Description
Ap	0-20/0-8	Very dark grayish brown (10 YR 3/2) stony fine sandy loam; weak medium granular structure; very friable; few medium trees and many fine brush roots; abrupt smooth boundary.
B21	20-46/8-18	Yellowish brown (10 YR 5/6) fine sandy loam; moderate, medium subangular blocky structure; very friable; many fine brush roots; clear smooth boundary.
B22	46-76/18-30	Pale olive (5 YR 6/4) silt loam; moderate medium subangular blocky structure; friable; clear smooth boundary.
IICx	76-122/30-48+	Olive gray (5 YR 5/2) and olive brown (2, 5 YR 4/4) silt loam; weak fine angular blocky structure; firm; many fine pores; discontinuous clay films on pores and coarse fragments.

Site:	2
Soil type:	Merrimac fine sandy loam
Classification:	Typic Dystrochrepts
Location:	Bristol County, Massachusetts. City of Taunton, Weir area. Borrow Pit just west of the intersection of Plain and Pratt Streets.
Vegetation and land use:	Scrub oak. Borrow pit.
Slope:	10 percent
Aspect:	Convex
Physiography:	Hummocky outwash
Parent material:	Stratified sand and gravel.

Horizon	Depth cm/in.	Description
A1+A2	0-7.5/0-3	Black (10 YR 2/1) fine sandy loam; weak medium granular structure; very friable; many medium oak roots; acid; clear smooth boundary.
B21	7.5-46/3-18	Strong brown (7.5 YR 5/8) fine sandy loam; moderate coarse subangular blocky structure; very friable; many medium oak roots; very acid; gradual smooth boundary.
B22	46-69/18-27	Light olive brown (2.5 YR 5/6) fine sandy loam; moderate coarse subangular blocky structure; very friable; few fine and very fine tree roots; very acid; clear smooth boundary.
IIC1	69-114/27-45	Light olive brown (2.5 YR 5/4) gravelly sand; structureless single grained; loose; fine and very fine oak roots; very acid; clear wavy boundary.

Horizon	Depth cm/in.	Description
IIC_2	114-190/45-75	Light olive brown (2.5 YR 5/4) stratified fine sand to gravel; structureless single grained; loose; few very fine tree roots; very acid; abrupt smooth boundary.
$IIIC_x$	190+/75+	Olive (5 YR 6/2) silt loam; strong coarse platy structure; extremely firm; discontinuous clay films on coarse fragments, continuous on pores; many small unconnected pores; very acid.

Site:	3
Soil type:	Paxton stony fine sandy loam
Classification:	Typic Fragiochrepts
Location:	Plymouth County, Massachusetts. Town of West Bridgewater. East side of Walnut Street 1/2 mile east of Manleys Corner.
Vegetation and land use:	White Pine, Town Conservation Land.
Slope:	5 percent
Aspect:	Flat
Physiography:	Ground morraine
Parent material:	Basal upper till.

Horizon	Depth cm/in.	Description
Ap	0-20/0-8	Dark brown (10 YR 3/3) stony fine sandy loam; moderate coarse subangular blocky structure; friable; many fine and medium brush roots; acid; abrupt smooth boundary.
B21	20-40.5/8-16	Yellowish brown (10 YR 5/6) fine sandy loam; weak coarse subangular blocky structure; friable; medium and large pine roots; very acid; clear smooth boundary.
B22	40.5-61/16-24	Yellowish brown (10 YR 5/6) fine sandy loam; weak coarse subangular blocky structure; friable; medium and large pine roots; very acid; gradual smooth boundary.
Cx	61-91/24-36+	Brownish yellow (10 YR 6/6) fine sandy loam; moderate medium platy structure; firm; few fine pine roots; discontinuous clay films on pores and coarse fragments; many fine pores; very acid.

Site: 4

Soil type: Paxton stony fine sandy loam

Classification: Typic Fragiochrepts

Location: Norfolk County, Massachusetts. Town of Stoughton. Foundation excavation north side of Ash Street.

Vegetation and land use: Scrub oak. Housing development.

Slope: 5 percent

Aspect: Convex

Physiography: Ground morraine

Parent material: Basal upper till.

Horizon	Depth cm/in.	Description
A1	0-5/0-2	Black (10 YR 2/1) fine sandy loam; weak medium crumb structure; friable; acid; abrupt smooth boundary.
A3	5-10/2-4	Dark yellowish brown (10 YR 4/4) fine sandy loam; moderate medium subangular blocky structure; friable; very acid; clear smooth boundary.
B21	10-40.5/4-16	Yellowish brown (10 YR 5/6) fine sandy loam; moderate coarse subangular blocky structure; very friable; very friable; very acid; gradual smooth boundary.
B22	40.5-61/16-24	Yellowish brown (10 YR 5/6) fine sandy loam; moderate medium subangular blocky structure; very friable; very acid; clear wavy boundary.
IIB3	61-76/24-30	Light yellowish brown (2.5 YR 6/4) fine sandy loam; weak fine subangular blocky structure; friable; very acid; abrupt smooth boundary.

Horizon	Depth	Description
	cm/in.	
IICx	76-122/30-48+	Light olive gray (5 YR 6/2) fine sandy loam; moderate medium platy structure; very firm; clay films on pores; silt caps on coarse fragments; very acid.

Site:	5
Soil type:	Paxton extremely stony fine sandy loam.
Classification:	Typic Fragiochrepts.
Location:	Town of Spencer, Worcester County, Massachusetts. Twelve hundred feet west along the high tension lines from Greenville Road and two hundred feet south from the high tension lines.
Land use and vegetation:	Wooded area - red oak, red maple, black cherry, white pine.
Physiography:	Drumlin.
Parent material:	Lower till.

Horizon	Depth cm/in.	Description
01	6.4-1.3/2-1/2-1/2	Non-decomposed organic matter.
02	1.3-0/1/2-0	Decomposed organic matter.
A1	0-12.7/0-5	Very dark grayish brown (10YR 3/2) fine sandy loam; moderate medium granular structure; very friable; abrupt wavy boundary.
B21	12.7-30.5/5-12	Dark yellowish brown (10YR 4/4) fine sandy loam; weak medium subangular blocky structure; clear smooth boundary.
B22	30.5-48.3/12-19	Olive brown (2.5Y 4/4) fine sandy loam; weak medium and coarse subangular blocky structure; friable; clear wavy boundary.
B23	48.3-73.7/19-29	Light olive brown (2.5Y 5/4) fine sandy loam; weak medium and coarse subangular blocky structure; friable; clear wavy boundary.

Horizon	Depth	Description
	cm/in.	
C_x	73.7-121.9/29-48	Light olive brown (2.5Y 5/4) exterior of peds; olive brown (2.5Y 4/4) interior of peds; fine sandy loam; segregated sand between peds; few medium distinct strong brown (7.5Y 5/6) mottles; moderate medium and coarse platy structure; firm; vesicular pores.

Site:	6
Soil type:	Paxton extremely stony fine sandy loam
Classification:	Typic Fragiochrepts
Location:	Hampshire County, Massachusetts. City of Northhampton, Leeds section. South side of Reservoir Road just opposite Roberts Meadow Reservoir.
Vegetation and land use:	Forest - young Birch, Red Oak.
Slope:	5 percent west
Physiography:	Top of till hill
Parent material:	Stony lower till.

Horizon	Depth cm/in.	Description
Ap	0-20/0-8	Very dark grayish brown (10 YR 3/2) extremely stony fine sandy loam; weak fine granular structure; very friable; many fine to coarse tree roots; medium acid; abrupt smooth boundary.
B21	20-61/8-24	Dark yellowish brown (10 YR 4/4) fine sandy loam; weak medium subangular blocky structure; friable; many fine to coarse tree roots; very acid; gradual wavy boundary.
B22	61-86/24-34	Dark grayish brown (10 YR 4/2) fine sandy loam; weak coarse subangular blocky structure; friable; some tree roots; very acid; abrupt smooth boundary.
Cx	86+/34+	Olive gray (5 YR 4/2) fine sandy loam; moderate coarse to medium platy structure; firm; very acid.

Series Descriptions

Established Series
Rev. WHG-EHS-JEW
1/75

BROADBROOK SERIES

The Broadbrook series consists of deep, well drained soils that formed in silt mantled acid glacial till. They are nearly level to sloping soils on glaciated drumloidal landforms. They typically have very friable, silt loam A and B horizons over a very firm and brittle fragipan.

Soil Family: Coarse-loamy, mixed, mesic Typic Fragiochrepts

Typical Pedon: Broadbrook silt loam - idle field
(Colors are for moist soil.)

Ap--0 to 6 inches, dark brown (10YR 3/3) silt loam; weak medium granular structure; very friable; many fine and medium roots; strongly acid; abrupt wavy boundary. (6 to 10 inches thick)

B21--6 to 14 inches, dark brown (7.5YR 4/4) silt loam; very weak coarse subangular blocky structure; very friable; few fine and medium roots; 1 percent coarse fragments; strongly acid; clear wavy boundary. (4 to 12 inches thick)

B22--14 to 26 inches, yellowish brown (10YR 5/4) silt loam; very weak coarse subangular blocky structure; very friable; few fine roots; 1 percent coarse fragments; strongly acid; clear wavy boundary. (8 to 16 inches thick)

IICx--26 to 60 inches, grayish brown (2.5Y 5/2) gravelly sandy loam; weak medium platy structure with some clean sand grains between plates; very firm, brittle; 20 percent angular coarse fragments; strongly acid.

Type Location: New London County, Connecticut; town of Montville, 3 miles northwest of the junction of Route 32 and Shantok Road in a borrow pit.

Range in Characteristics: Thickness of the solum and depth to the lithologic discontinuity ranges from 20 to 36 inches. Depth to bedrock is more than 60 inches. Gravel size angular fragments above the fragipan range from essentially none to 20 percent and in the fragipan from about 5 to 30 percent. Cobblestones and stones range from 0 to 5 percent in the solum and 0 to 15 percent in the C horizon. The soil ranges from very strongly acid to medium acid throughout.

The Ap and A1 horizons have hues of 7.5YR or 10YR, values of 3 or 4 and chroma of 2 to 4. They are silt loam, loam or very fine sandy loam in the fine earth fraction.

The B horizon has hues of 7.5YR or 10YR, values of 4 or 5 and chroma of 4 or 6 in the upper part and hues of 7.5YR through 2.5Y, values of 4 or 5 and chroma of 3 to 6 in the lower part. It has a few mottles just above the fragipan in some pedons. The B horizon is silt loam, loam, or very fine sandy loam with less than 10 percent clay and more than 50 percent silt plus very fine sand in the fine earth fraction. It has very weak subangular blocky or weak granular structure or it is massive.

The IICx horizons have hues of 2.5YR to 2.5Y, values of 2 to 6 and chroma of 2 to 6. They are loam, fine sandy loam, or sandy loam in the fine earth fraction. They have weak medium or thick platy structure or they are massive.

Competing Series and Their Differentiae: The Bath, Bernardston, Braceville, Broadalbin, Compton, Ira, Lackawanna, Ludlow, Mardin, Millis, Montauk, Nantucket, Newport, Paxton, Pittstown, Rainbow, Scituate, Sodus, Swartswood, Wellsboro, Wethersfield and Wurtsboro series are in the same family. Bath, Braceville, Broadalbin, Ira, Lackawanna, Mardin, Sodus, Swartswood, Wellsboro, Woodbridge and Wurtsboro soils have Bx horizons. Bernardston and Pittstown soils have coarse fragments dominated by phyllite, shale or slate and lack a lithologic discontinuity at the top of the fragipan. Compton and Newport soils have hues of 2.5Y or 5Y throughout the B horizon. Ludlow and Wethersfield soils have hues of 5YR or redder throughout the B horizon and fragipan. Hillis and Scituate soils are gravelly loamy fine sand to very gravelly loamy coarse sand in the fragipan. Montauk, Paxton and Woodbridge soils have B horizons of loam, fine sandy loam or sandy loam with less than 50 percent silt plus very fine sand. Nantucket soils are clay loam or clay in the lower part of the series control section. Rainbow soils are mottled in the B22 horizon.

The Buckland, Essex, Narragansett and Poquonock series are similar soils in related families. Buckland soils have a frigid temperature regime. Essex and Poquonock soils have sandy particle-size control sections. Narragansett soils lack a fragipan.

Geographic Setting: Broadbrook soils are nearly level to sloping soils on glaciated drumloidal land forms. Slopes generally range from 2 to 15 percent in gradient. The soils formed in a mantle of silty windblown or waterlaid deposits over acid glacial till from a wide variety of rocks. Depth to bedrock is normally more than ten feet. The climate is humid and cool temperate. Mean annual air temperature ranges from about 45° to 52° F; mean annual precipitation from about 42 to 50 inches; and frost-free days from about 135 to 190.

Geographically Associated Soils: These are the competing Ludlow, Narragansett, Paxton, Poquonock, Rainbow, Wethersfield and Woodbridge series and the Belgrade, Birchwood, Charlton, Cheshire, Enfield, Hartland, Hinckley, Merrimac and Wapping soils. Belgrade, Enfield, Hartland, Hinckley and Merrimac soils are on nearby terraces. Birchwood soils are sandy and Charlton, Cheshire and Wapping soils lack a fragipan.

Drainage and Permeability: Broadbrook soils are well drained and runoff is medium to rapid. Permeability is moderate above the fragipan and slow or very slow in the fragipan.

Use and Vegetation: Most areas are cleared and used for growing hay, pasture, silage corn, and orchards and some tobacco, nursery stock, and other crops. Stony areas are mainly in forest or used for pasture. Principal species in woodlots include white and red oak, white ash, hickory, red and sugar maple, white pine, and hemlock.

Distribution and Extent: Connecticut, Massachusetts, eastern New York and Rhode Island. The series is of moderate extent.

Series Established: Hartford County, Connecticut, 1959.

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Established Series
Rev. SALP 3/8/71

PAXTON SERIES

The Paxton series is a member of the coarse-loamy, mixed, mesic family of Entic Fragiorthods. These soils have very dark grayish brown fine sandy loam surface horizons and yellowish brown and light olive brown fine sandy loam B horizons underlain by a fragipan at depths of 15 to 36 inches.

Typifying Pedon: Paxton fine sandy loam-hayfield (Colors are for moist soil)

Ap -- 0-8" -- Very dark grayish brown (10YR 3/2) fine sandy loam; weak, fine, granular structure; friable; many roots; 5 percent gravel; medium acid; abrupt smooth boundary; (5 to 9 inches thick.)

B21 -- 8-11" -- Yellowish brown (10YR 5/6) fine sandy loam; weak, medium, granular structure; friable; many roots; 5 percent gravel; slightly acid; abrupt wavy boundary; (2 to 6 inches thick.)

B22 -- 11-22" -- Light olive brown (2.5Y 5/4) fine sandy loam; weak, thick, platy structure; firm; common roots; 15 percent gravel; medium acid; clear wavy boundary; (8 to 11 inches thick.)

CX -- 22-41" -- Grayish brown (2.5Y 5/2) crushed mass is olive (5Y 5/3) fine sandy loam; moderate, thick, platy structure; very firm; no roots; 15 percent gravel; medium acid.

Type Location: Strafford County, New Hampshire, town of Strafford. Caverly Hill about 2 miles southeast of Bow Lake Village on Leighton Farm. Site located in hayfield about 150 feet south of farmhouse. USGS Mt. Pawtuckaway 15' quadrangle; 43°13'50"N and 71°07'10"W. State Plane Coordinates; Zone 0, E/W 646200, N/S 267000.

Range in Characteristics: The depth to the fragipan ranges from 15 to 36 inches. Coarse fragments in both the solum and fragipan range from

5 to 30 percent. The silt content throughout the solum and C horizons ranges up to 45 percent. Reaction of the solum and underlying till ranges from strongly to slightly acid. In undisturbed pedons, A1 horizon moist colors are of 10YR hue with values of 2 or 3 and chromas of 1 or 2. Ap horizon colors are of hue 10YR with values of 3 or 4 and chromas of 2 to 4. Textures of A horizons are dominantly fine sandy loam or loam but range to sandy loam or gravelly analogues. Structure is dominantly weak, fine or medium granular. B21 horizon colors are dominantly of hue 10YR with value of 5 and chromas of 6 and 8 and of hue 7.5YR with value of 5 and chromas of 6 and 8. B22 horizon colors are of hue 2.5Y with value of 5 and chromas of 3 and 4 and of hue 10YR with value of 5 and chromas of 4 and 6. Textures in the B2 horizons are dominantly fine sandy loam or loam but range to sandy loam or gravelly analogues. The structure of B2 horizons is dominantly weak, fine or medium granular but ranges to weak, thin to thick, platy in the lower B2. An A'2 horizon is present in some pedons. A few mottles occur immediately above the fragipan or within the fragipan in some pedons. C horizon colors are of hue 2.5Y with values of 4 to 6 and chromas of 2 and 4 and of hue 5Y with values of 4 to 6 and chromas of 2 and 3. Texture of C horizons is dominantly fine sandy loam or loam or gravelly analogues but ranges to sandy loam or gravelly sandy loam. Structure of C or CX horizons is dominantly weak or moderate, medium or thick platy but ranges to thin platy or is massive. Consistence of CX horizons is firm or very firm with brittleness characteristics of fragipans.

3-Paxton Series

Competing Series and Their Differentiae: The Bernardston, Broadbrook and Newport are members of the same family. Bernardston soils have a higher silt content in the solum and fragipan. Broadbrook soils have a silty mantle overlying a loamy fragipan. Newport soils have B21 horizons with color values less than 5, moist, and hues less red than 10YR. Closely related soils are the Charlton, Essex, Marlow and Woodbridge. Charlton soils lack a fragipan Essex soils have coarse texture. Marlow has at least 1.2 percent organic carbon in the upper 4 inches of the spodic horizon and is colder. Woodbridge soils have mottles in the lower spodic horizon.

Setting: The Paxton soils occupy the nearly level to sloping positions on drumlins and sloping areas of glaciated uplands. Slopes generally range from 0 to 25 percent. The regolith is compact acid stony glacial till of Wisconsin age that is derived mainly from mica schist and granite. The climate is humid and cool temperate. Mean annual precipitation ranges from 37 to 49 inches and the frost free season from 115 to 180 days.

Principal Associated Soils: The moderately well drained Woodbridge, poorly drained Ridgebury and very poorly drained Whitman are members of the same drainage sequence. Common associates are the Charlton, Sutton and Leicester, but these soils all lack a fragipan. Hollis soils have bedrock within depths of 20 inches but also occur in close association with the Paxton.

Drainage and Permeability: Well-drained. Runoff is medium or rapid depending on slope. Permeability is moderate above the fragipan and slow in the fragipan. Water moves laterally along the top of the fragipan.

Use and Vegetation: Areas cleared of stones are used mainly for hay and pasture. Apple orchards and potatoes are also common crops. In wooded areas, the principal species are red oak, sugar maple, hemlock and white pine.

Distribution and Extent: New England and eastern New York. The series is of large extent, with an area of about 600,000 acres.

Series Established: Worcester County, Massachusetts, 1922.

Remarks: Formerly classified as a Brown Podzolic in the 1938 classification system.

Additional Data: The Paxton benchmark soils report. Bulletin 662, December 1963, issued by Connecticut Agricultural Experiment Station, New Haven, Connecticut.

National Cooperative Soil Survey
U. S. A.

Established Series
Rev. DGG
6/6/76

MERRIMAC SERIES

The Merrimac series consists of deep, somewhat excessively drained soils formed in glacial outwash. They are nearly level to very steep soils on landforms formed by glacial meltwater. They typically have a very dark grayish brown fine sandy loam Ap horizon, brown to dark yellowish brown fine sandy loam to gravelly loamy sand B horizons underlain by yellowish brown gravelly sand IIC horizon at about 26 inches.

Soil Family: Sandy, mixed, mesic Typic Dystrochrepts

Typical Pedon: Merrimac fine sandy loam - cultivated
(Colors are for moist soil.)

Ap--0 to 10 inches, very dark grayish brown (10YR 3/2) fine sandy loam; weak fine and medium granular structure; very friable; many grass roots; 10 percent fine gravel; strongly acid; abrupt smooth boundary. (6 to 14 inches thick)

B21--10 to 15 inches, brown (7.5YR 4/4) fine sandy loam; weak fine and medium granular structure; very friable; common grass roots; 10 percent fine gravel; strongly acid; clear wavy boundary. (2 to 12 inches thick)

B22--15 to 22 inches, dark yellowish brown (10YR 4/4) sandy loam; weak fine and medium granular structure; very friable; few grass roots; 15 percent gravel; strongly acid; clear wavy boundary. (4 to 12 inches thick)

B23--22 to 26 inches, dark yellowish brown (10YR 4/4) gravelly loamy sand; very weak fine granular structure; very friable, loose; few grass roots; 25 percent gravel; medium acid; clear wavy boundary. (0 to 10 inches thick)

IIC--26 to 60 inches, 80 percent yellowish brown (10YR 5/4) and 20 percent dark grayish brown (10YR 4/2) very gravelly sand; single grain; loose; stratified; few grass roots in upper 6 inches; 40 percent gravel and 10 percent cobblestones; medium acid.

Type Location: Franklin County, Massachusetts. Town of Leverett, 2-3/4 miles south-southeast of Montague Village, 1/8 mile southeast of Cranberry Pond, just west of Route 63.

Range in Characteristics: Solum thickness ranges from 18 to 30 inches. Rock fragments are mainly granitic or gneissic, but up to 25 percent of the rock fragments are flat, fine-grained slate, shale, or phyllite fragments. The upper part of the solum commonly has 5 to 20 percent gravel and the lower part 5 to 30 percent. The substratum contains 25 to 55 percent gravel and 5 to 15 percent cobblestones. Total volume of rock fragments in the particle-size control section is less than 35 percent. Clay content is less than 18 percent. The soil, unless limed, ranges from extremely acid through medium acid.

The Ap horizon has hue of 7.5YR and 10YR, value of 3 or 4, and chroma of 2 through 4. In undisturbed areas a 1 to 4 inch thick A1 horizon has similar hue with value of 2 or 3, and chroma of 1 or 2. Some pedons have thin, lighter colored A2 horizons. The A horizons are fine sandy loam, sandy loam, or very fine sandy loam.

The B horizons have hue of 7.5YR or 10YR in the upper part and 7.5YR through 2.5Y in the lower part. Value ranges from 3 through 6 and chroma 3 through 8. The upper part of the B horizon is fine sandy loam, sandy loam, or very fine sandy loam. It has very weak or weak, very fine to medium granular structure, or the horizon is massive. The lower part of the B horizon is sandy loam, gravelly sandy loam, loamy sand, or gravelly loamy sand. Sandy loam textures do not extend below depth of 27 inches, but a minimum thickness of 5 inches of sandy loam overlies any lower B or IIC horizons that are loamy fine sand or coarser. The B subhorizon that lies above the IIC horizon in many pedons is single grain.

The IIC horizons have hue of 10YR through 5Y, and range widely in value and chroma. The IIC horizons consist of stratified sand, gravel, and cobblestones and have a weighted testure of gravelly sand or very gravelly sand.

Competing Series and Their Differentiae: The Hartford series is the only other member of the same family. The Agawam, Canton, Copake, Gloucester, Haven, Hinckley, Ninigret, Riverhead, Sudbury, and Warwick series are in related families. The Agawam, Canton, and Haven soils have contrasting particle-size control sections. Copake soils have carbonates within the soil. Gloucester, Hinckley and Warwick soils average more than 35 percent rock fragments between depths of 10 and 40 inches. Hartford soils have hues of 5YR or redder in the B horizon. Ninigret and Sudbury soils have low chroma mottles in the B horizon within 24 inches of the surface. Riverhead soils have dominant texture of sandy loam or fine sandy loam with more than 50 percent fine sand or coarser, in the 10 to 40 inch layer.

Geographic Setting: Merrimac soils are level to gently undulating and very steep soils on glacial outwash plains and valley trains, and associated kames, eskers, stream terraces and water deposited parts of moraines. The steeper slopes are on the margin escarpments of terraces and plains, and on eskers and kames. Slope gradients range from 0 to 60 percent. The soils formed in water sorted gravelly and sandy material derived mainly from granitic, gneissic and some schistose rocks. Mean annual precipitation ranges from 28 to 55 inches; mean annual air temperature from 45°F. to 50°F.; mean growing season, from 120 to 200 days.

Geographically Associated Soils: These are the competing Agawam, Hinckley, and Sudbury series and the Scarboro, Walpole and Windsor soils. Scarboro soils are very poorly drained, Walpole soils are poorly drained and the excessively drained Windsor soils have loamy fine sand to medium sand textures in the B horizon.

Drainage and Permeability: Somewhat excessively drained. Runoff is slow or medium and internal drainage is rapid. Permeability is moderately rapid or rapid in the solum and rapid in the substratum.

Vegetation and Use: Mainly cultivated and used for growing hay, pasture, silage, corn, or truck crops. It is used to grow tobacco in the Connecticut Valley of Massachusetts and Connecticut. Forested areas are mostly white pine, gray birch, hemlock, red maple, and red, black, white, and scarlet oaks.

Distribution and Extent: Massachusetts, Connecticut, Maine, New Hampshire, New York, Vermont and Rhode Island. The series is extensive.

Series Established: Merrimack County, New Hampshire, 1906.

Remarks: This revision is a result of reclassification of many mesic soils from Haplorthods to Dystrochrepts. (NETSC Advisory SOILS-7, June 16, 1975)

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